CHAPTER 20

MAGNETISM

Magnetism has been mentioned briefly in Chapter 6 as an effect of electric current. In this Chapter the properties of bar magnets and magnetic fields will be examined so that the knowledge gained may be used in later studies to understand more fully the magnetic effects of electric current. The magnetic effect of electric current is of vital importance to the electrical industry, for without it, such every day accepted functions such as the generation of electricity would not be possible.

20.1 THE BAR MAGNET

Students are aware that the earth has what is called a North and South pole. Navigation around the world is possible because of the compass, a device which aligns itself so that it points in the direction of the poles. This alignment of the compass is due to invisible lines of force which exist between the two poles. The earth is a giant magnet and the invisible lines of force between the poles is called a magnetic field.

The earth's magnetic system can be simulated in the bar magnet. The bar magnet is a piece of a suitable material which has been treated so that a north and south pole have been formed at the ends of the material. This magnet exhibits lines of force, or a magnetic field, similar to the field around the earth. (Figure 20.1).

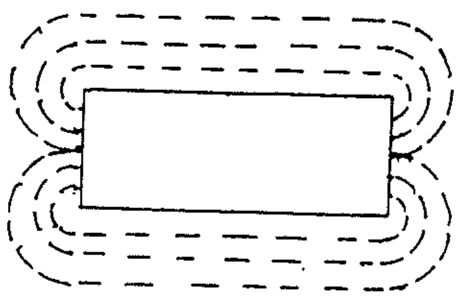

Figure 20.1

The field is shown on a two dimensional plane, but is, in fact, totally surrounding the magnet. A compass placed anywhere within the field will react the same as a compass placed in the earth's magnetic field. A magnetic field can only exist if there is a minimum of one north pole and one south pole.

The direction of the lines of force in a magnetic field is from north to south **outside** the magnet. This direction is determined from the laws of magnetic poles, which state –

1. Like poles repel
2. Unlike poles attract

If an imaginery single north pole is placed in a magnetic field, due to the laws of magnetic poles it would be repelled from the north pole of the magnet and attracted to the south pole of the magnet. (Figure 20.2)

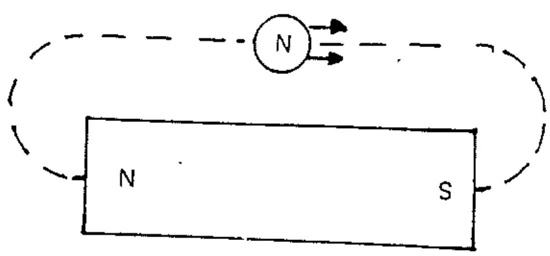

Figure 20.2

The direction an imaginary north pole moves if placed in a magnetic field is known as the positive direction of that field. The direction of the field of a typical bar magnet is shown in Figure 20.3.

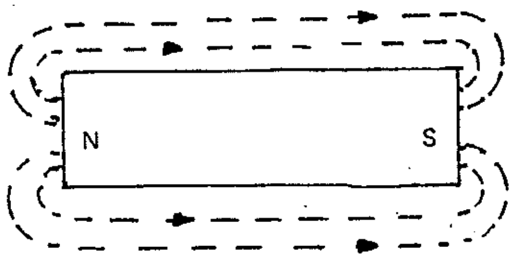

Figure 20.3

20.2 HORSESHOE MAGNETS

The magnetic field created by a pair of unlike poles can be concentrated into a small area by casting the metal of the magnet into the shape of a horseshoe. (Figure 20.4).

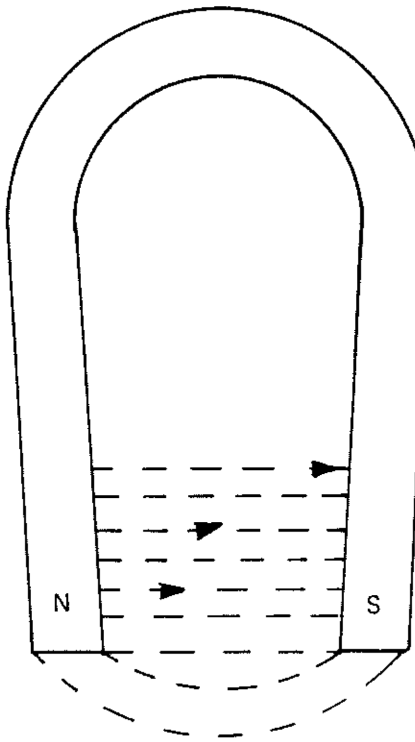

Figure 20.4

The field system produced by unlike adjacent magnetic poles is used in electrical machinery to produce mechanical rotation and/or electrical power.

20.3 MAGNETIC MATERIALS

It has been said that atomic structure is similar to the solar system. The earth orbits the sun, but at the same time, the earth rotates about its own axis. The same applies to electrons as they orbit the nucleus. In most metals each sub-shell is filled before electrons exist in the next sub-shell. Because the maximum number of electrons in each sub-shell is an even number, the electrons are said to be paired. A certain group of metals, however, contain electrons in the outer main shell before the next inner main shell is completed. This results in what is known as unpaired electrons. These metals possess good magnetic properties, the greater the number of unpaired electrons being in the sub-shell previously mentioned, the better the magnetic property of the material. The atomic structure of this group is shown in Table 20.1.

Table 20.1

SHELL	K	L	M	N
Maximum number in each sub-shell	2	2 6	2 6 10	2 6 10 14
Manganese	2	2 6	2 6 5	2 0 0 0
Iron	2	2 6	2 6 6	2 0 0 0
Cobalt	2	2 6	2 6 7	2 0 0 0
Nickel	2	2 6	2 6 8	2 0 0 0

Manganese has five unpaired electrons, iron has four, cobalt has three while nickel has two. These metals make good magnetic material and are referred to a ferromagnetic material. Other materials such as oxygen, aluminium, copper and air have most of their electrons paired and are poor magnetic materials.

20.4 MAGNETIC PROPERTIES OF MATERIALS

Magnets are classified as either temporary or permanent magnets depending upon whether they lose or retain their magnetic influence after the magnetising force has been removed. The property of retaining a magnetic field is known as the retentivity of the material. Most magnets have iron as the main material. The addition of, or lack of, other materials in the molten state determines whether the final product will become a temporary or permanent magnet. Temporary magnets are usually manufactured from 'soft iron', iron to which no additives have been included. Permanent magnets have such materials as carbon, copper or nickel added to the molten iron, the resulting material is known as 'hard iron'. Because of their hardness, permanent magnets are difficult to machine and often have to be caste into their individual patterns.

The ease with which a material allows the passage of lines of force is called permeability (μ). Permeability in magnetism is similar to the conducting ability of a material in electricity. Ferro-magnetic materials have high permeabilities, while non-magnetic materials have low permeabilities. A comparison of the relative permeabilities of some materials is given in Table 20.2.

Table 20.2

MATERIAL	PERMEABILITY (μ_r)
Copper	0.9999
Air	1.000
Cobalt	170
Nickel	1000
Iron	7000
Permalloy (Nickel Iron)	80 000

Magnetic materials under the influence of a magnetising force, provided by a coil with 'N' number of turns and an increasing current 'I', will allow different numbers of lines of force to build up within the material. (Figure 20.5).

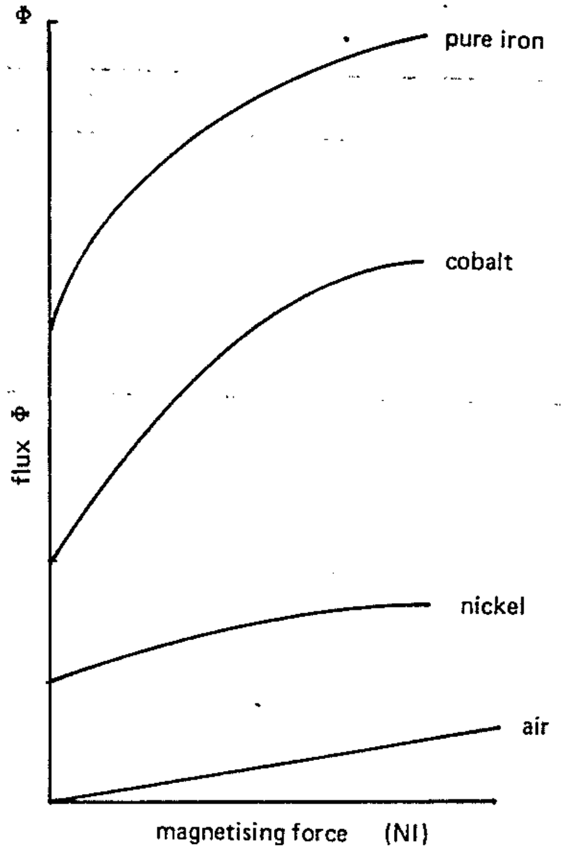

Figure 20.5

The total number of lines of force in a magnetic field is known as its flux (Φ). From figure 20.5 it can be seen that for the same magnetising force more lines of force will build up in pure iron than in cobalt or nickel or air. This implies that pure iron has the highest permeability of the four.

The opposition to the building up of the lines of force of a magnetic field is termed reluctance. This acts the same way to lines of force as resistance acts to electric current. Magnetic materials have low reluctance and non-magnetic materials have high reluctance.

The ability to retain the magnetic effect after the magnetising force has been removed is called retentivity. Soft ferro-magnetic materials have low retentivity while hard ferro-magnetic materials have high retentivity.

20.5 LAWS OF MAGNETIC LINES OF FORCE

The laws of magnetic lines of force state –

1. They are continuous. Lines of force passing from north to south outside a magnet pass from south to north inside the magnet.
2. They are elastic. Lines of force may be distorted into any shape, but will always return to their shortest length if free to do so.
3. They do not cross.
4. They will pass through non-magnetic substances, unaffected.

These laws apply regardless of whether the magnetic field exists in a bar magnet or the most complicated piece of electrical equipment.

20.6 MAGNETIC FIELDS BETWEEN BAR MAGNETS

Figure 20.6 illustrates the directions of the lines of force if two magnets are positioned in close proximity.

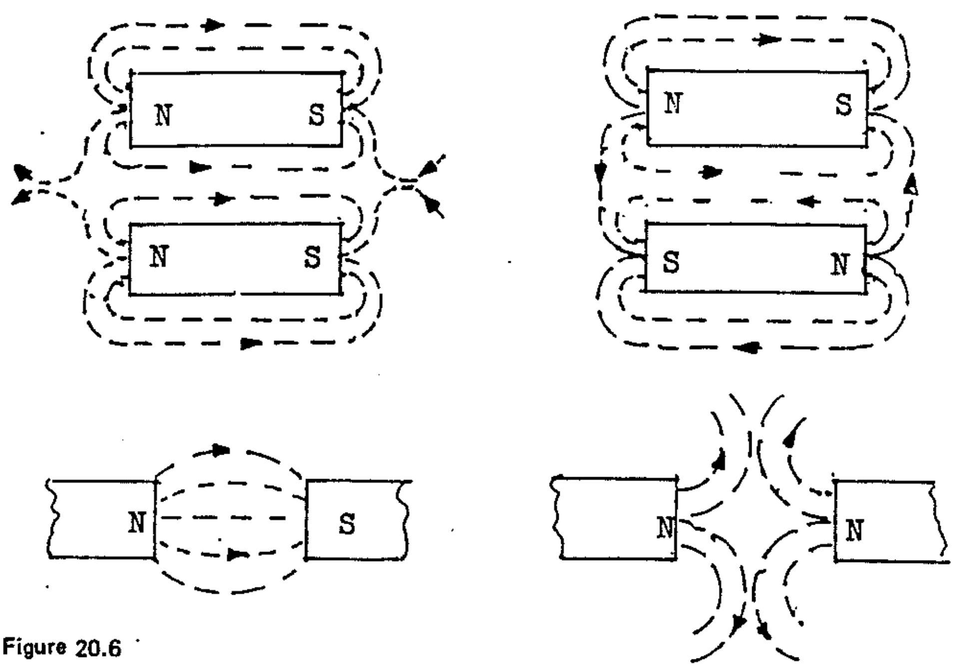

Figure 20.6

Observation of the fields in 20.4 will show that they conform with the previous theory explained in this chapter.

20.7 SCREENING

The field from a magnet may spread over a wide area depending on the strength of the magnet. Electric current will always take the path of least opposition or resistance. Likewise magnetic line of force will always take the path of least reluctance. If a piece of ferro-magnetic material is placed in a magnetic field, the lines of force will take the low reluctance path of the material in preference to the high reluctance path of the air. (Figure 20.7)

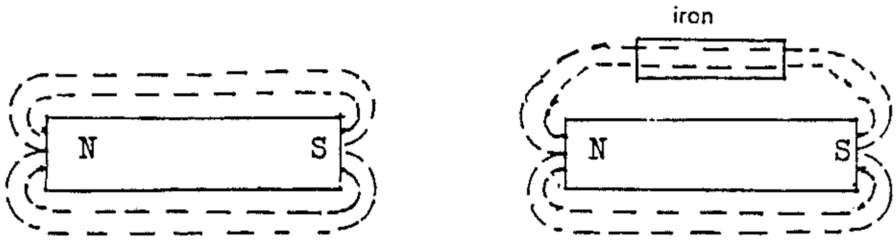

Figure 20.7

This fact can be utilised to isolate areas from magnetic fields by enclosing the areas with a low reluctance path. (Figure 20.8).

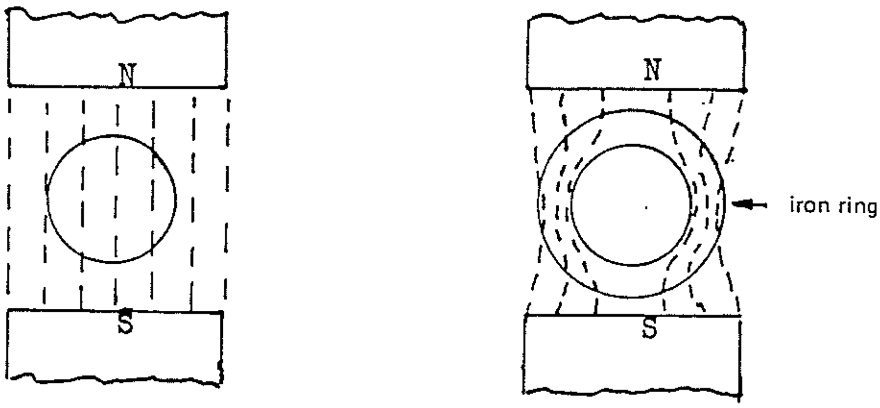

Figure 20.8

The lines of force which would normally traverse. the circled area are diverted around the area by the iron ring, leaving the area free of any magnetic influence. This is called screening or shielding. Screening is used to protect instruments or mechanisms from the effects of stray magnetic fields.

TUTORIALS 1.20 (Revision Tutorials)

(1) The resistance of a coil wound with copper wire is 52 ohms at 20°C. Calculate its resistance at 34°C if the temperature coefficient of resistance of copper is 0.004 per degree C.

(2) A copper conductor 100 m long has a resistance of 0.43 ohms. Calculate the area of the conductor if the resistivity of copper is 1.72×10^{-8} ohm metre.

(3) Three resistors of 10. 15 and 30 ohms are connected in parallel to a 120 volt d.c. supply. Calculate the:-

(a) total resistance

(b) current drawn from the supply

(4) A electric jug containing 2 litres of water takes 10 minutes to raise the water temperature from 20°C to 95°C. If the jug draws 5 amperes from a 240 volt d.c. supply, calculate its efficiency.

(5) Determine the temperature change required to increase the length of a 500 mm long copper bar to 501 mm if the coefficient of expansion of copper is 17×10^{-6} per °C.